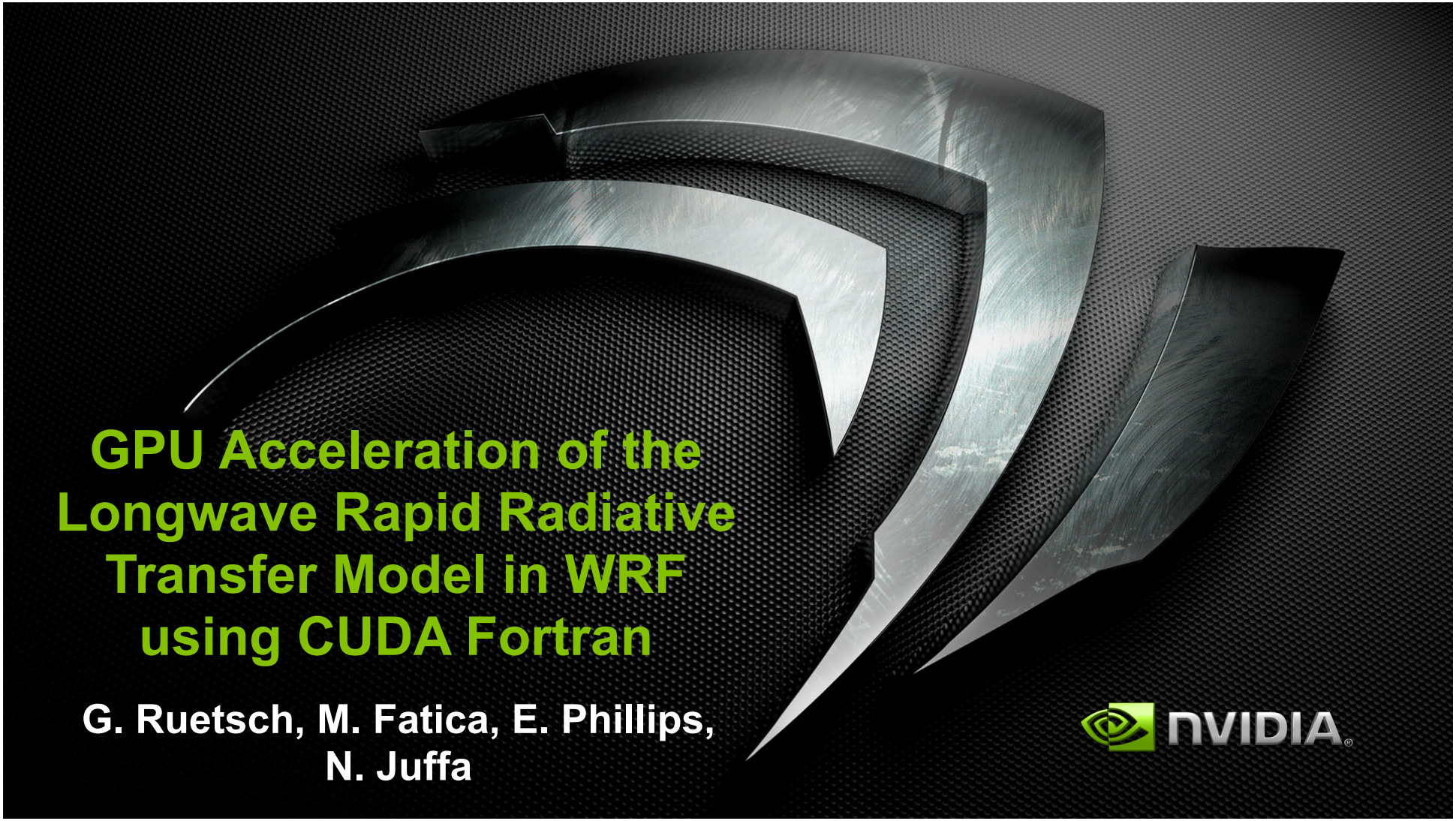

GPU Acceleration of the Longwave Rapid Radiative Transfer Model in WRF using CUDA Fortran
G. Ruetsch, M. Fatica, E. Phillips, N. Juffa
NVIDIA

Outline

- WRF and RRTM
- Previous Work
- CUDA Fortran Features
- RRTM in CUDA Fortran
- Results

Hot of the Press

- Batched Solver for Small Matrix Problems

WRF and RRTM

- WRF (Weather Research and Forecast) is a mesoscale numerical weather prediction code designed for both operational forecasting and the research community with a broad spectrum of applications and multiple physics options.

- Longwave RRTM (Rapid Radiative Transport Model) is an optional model that computes the energy transfer through the atmosphere due to electromagnetic radiation
  - Uses look-up tables for efficiency
  - Separates calculation into 16 spectral bands

RRTM - Previous Work

- RRTM proposed as benchmark kernel
  - http://www.mmm.ucar.edu/wrf/WG2/GPU/
  - Contains only CPU code
- Initial GPU port to CUDA Fortran on PGI's website
  - http://www.pgroup.com/resources/accel_files/list.htm
  - One of several WRF components on PGI Accelerator Files site
  - Contains CUDA Fortran source code and white paper
  - Based on C1060 and early version (10.1) of the CUDA Fortran compiler

CUDA and CUDA Fortran

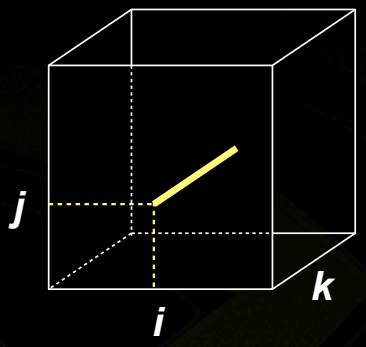
- CUDA programming model
  - Heterogenous programming model
    - Use both CPU and GPU, which have different memory spaces
    - Allows for incremental development
  - Scalable programming model
    - Programs runs on any number of processors without recompiling
    - Write a program for one thread, instantiate on many parallel threads
- CUDA Fortran is the Fortran analog of CUDA C
  - Implemented in PGI's Fortran compiler
  - Program host and device code similar to CUDA C
  - Host code is based on Runtime API
  - Fortran language extensions to simplify data management

RRTM Components

- RRTM has the following steps
  - INIRAD: computes the ozone mixing ratio distributions
  - MM5ATM: provides atmospheric profiles
  - SETCOEF: calculates various quantities needed for the radiative transfer algorithm
  - GASABS: calculates gaseous optical depths and Planck functions
    - Computed in 16 spectral bands
  - RTRN: calculate the radiative transfer for both clear and cloudy columns
- Radiation only depends on data in the same vertical column
  - GPU exploits this parallelism

Data Layout

CPU Layout

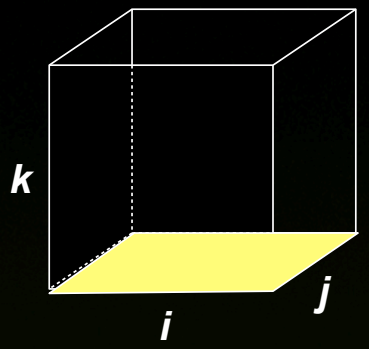


A(i,k,j)

Outer loops over (i,j)

Extract 1D arrays in k and send to RRTM

GPU Layout



Reorder to A(i,j,k) after transfer

For rtrn():
*launch nx*ny threads, each thread calculates one column*

All other routines:
*launch nx*ny*nz threads*

Recent Changes

- Fermi architecture
  - *-Mcuda=cc20*
  - L1 cache
    - 64KB allotment set to 48KB L1 cache and 16KB shared memory
  - Lookup tables changed from *constant* to *device* arrays
    - *constant* still used for physical constants (scalar values)
- CUDA Fortran additions
  - Pinned host memory used for large arrays (faster transfer, enables asynchronous transfers)
    - add *pinned* attribute to variable declarations

Results

- Performed on system with
  - Two quad-core Xeon X5550 CPUs (2.67 GHz)
  - Tesla M2050 (Fermi) GPU (448 cores, 1.15 GHz, 3GB memory)
  - Tesla M2090 (Fermi) GPU (512 cores, 1.3 GHz, 6GB memory)
  - PGI 11.8 compilers
  - CPU code from http://www.mmm.ucar.edu/wrf/WG2/GPU/
    - Utilizes a single CPU core
- Input data is on a (*nx*,*nz*,*ny*) mesh with *nx*=73, *nz*=28, *ny*=60

Results

	Previous Study		*Current Results*				
	X5440	Tesla C1060	X5550	Tesla M2050		Tesla M2090	
	-fast	Baseline	-fast	Baseline	Modified	Baseline	Modified
Overall time (*ms*)	703	83	479	44	38	41	34
% time in gasabs()	56%	31%	52%	21%	22%	21%	21%
% time in rtrn()	28%	46%	27%	48%	45%	44%	43%

Tesla M2050/M2090 Baseline: code from previous study, recompiled with 11.8
Tesla M2050/M2090 Modified: items in Recent Changes implemented

Conclusions and Future Work

- Conclusions
  - Good speedup for a small problem
  - Data reordering is key
    - Leverage separate memory space (host data unchanged)
    - Reordering fast on device
- Future Work
  - Add asynchronous data transfers to hide communication
  - Textures are coming to CUDA Fortran
    - Possibility for lookup tables
  - Utilize CPU and GPU

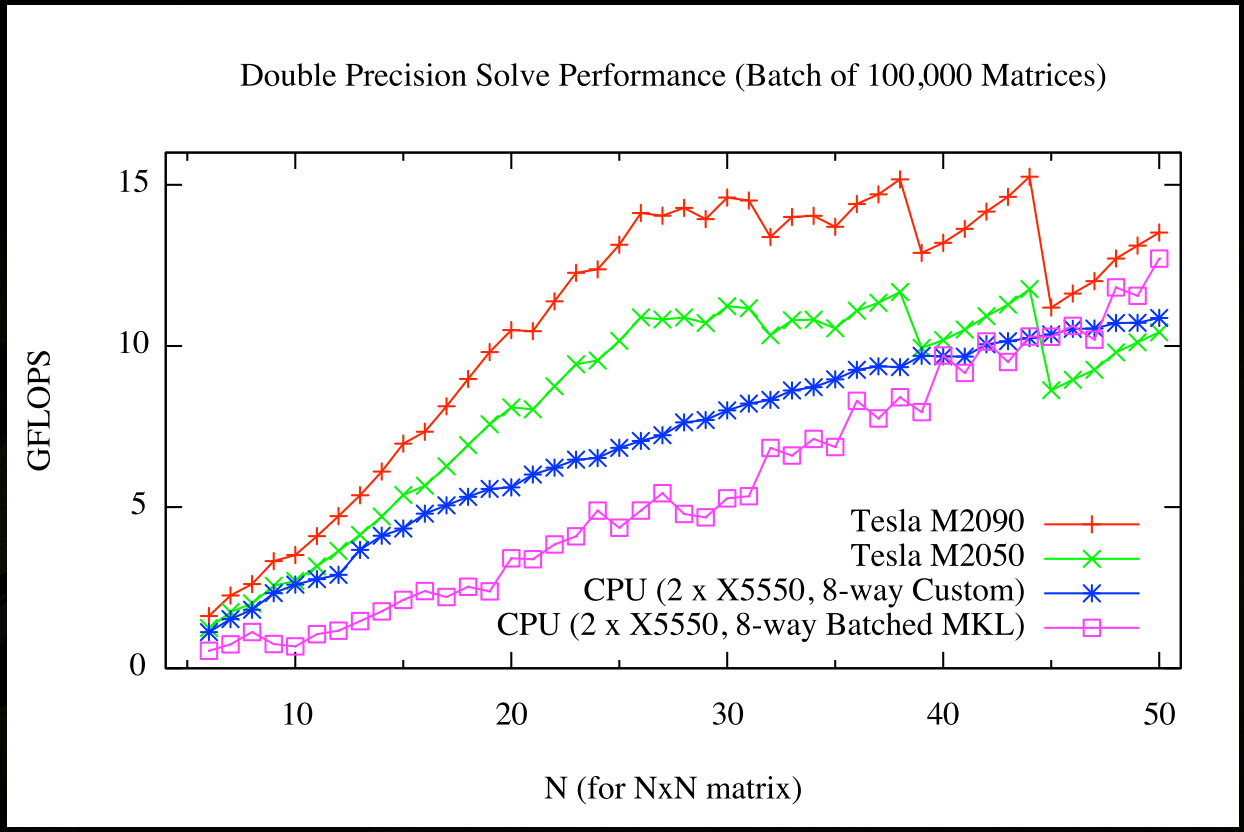
Batched Solver for Small Matrices

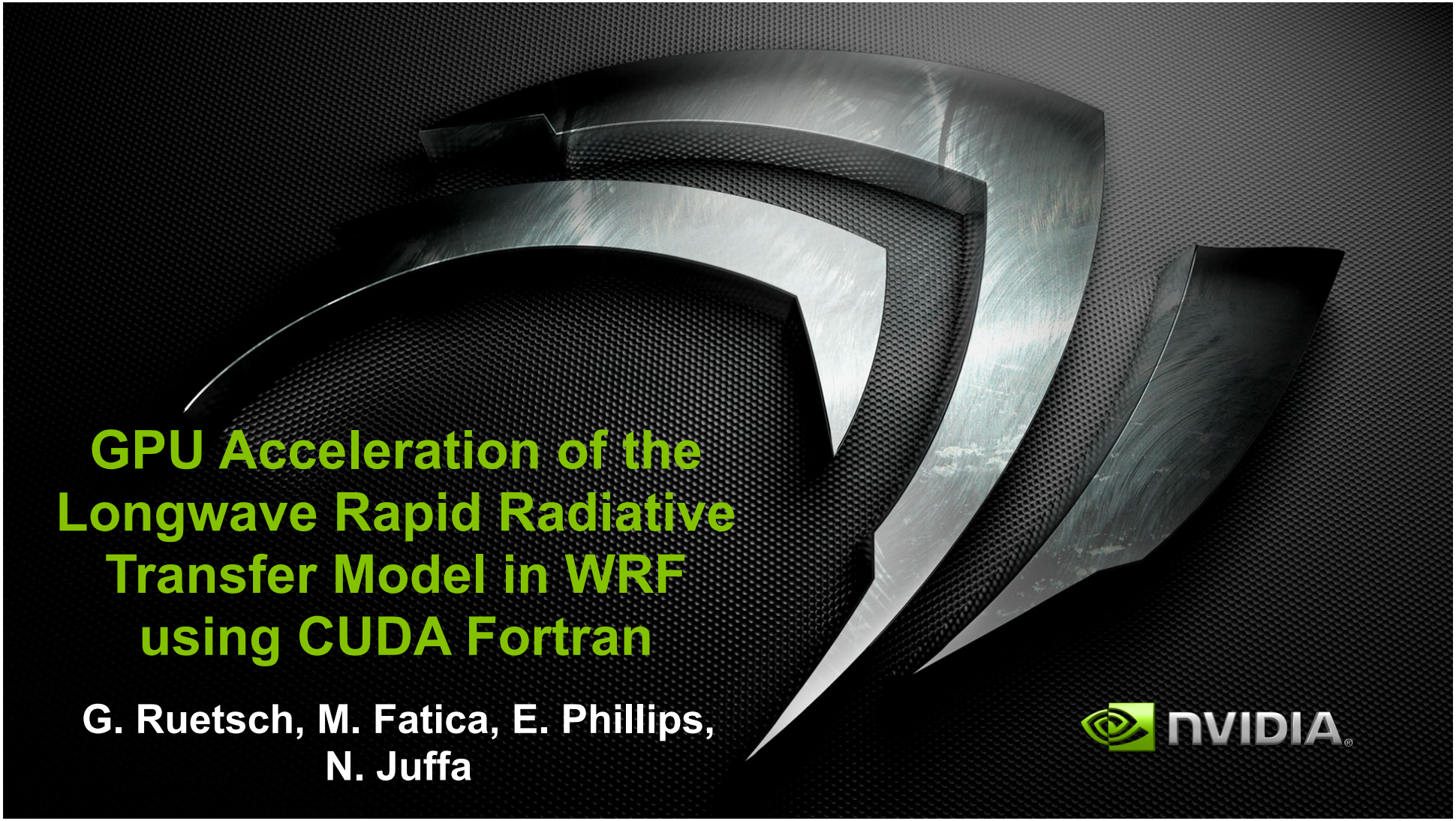
- Motivated by chemical simulation containing ~20 species
  - Independent system is solved at each grid point
- LU decomposition, Gaussian and Gauss-Jordan elimination
  - Dense matrices
  - Partial pivoting
  - Routine chosen based on matrix size and hardware
- Double precision (and double-complex)
- Code will be available at http://nvdeveloper.nvidia.com

Batched Solver Implementation

- Each system is mapped to a thread block
- Each thread in a thread block can work on multiple matrix elements
  - One matrix element per thread most efficient for small matrices
- Pivoting via two-stage process
  - Configurable number of threads finds maximum of elements assigned to them, and write these intermediate values to shared memory
  - All threads redundantly find the maximum of the intermediate values
  - Can be turned off for diagonally dominant matrices

Batched Solver Performance




GPU Acceleration of the Longwave Rapid Radiative Transfer Model in WRF using CUDA Fortran
G. Ruetsch, M. Fatica, E. Phillips, N. Juffa
NVIDIA